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(54) Fuzzy device for image noise reduction

(57) Fuzzy device for image noise reduction, comprising: interface means adapted to retrieve the gray level of a pixel to be processed of an image and of neighbouring pixels; difference means connected to said interface means adapted to generate a difference of the gray levels between said neighbouring pixels and said pixels to be processed; fuzzy flat area smoothing means connected to said difference means adapted to perform a low-pass smoothing of an almost homogeneous region defined by said pixel and by said neighbouring pixels; edge preserving smoothing means connected to said difference means adapted to perform low-pass filtering on a high-pass information region defined by said pixel and by said neighbouring pixels; region voter means connected to said interface means adapted to give a measure for considering whether said region defined by said pixel and said neighbouring pixels is almost homogeneous; and soft switching means connected to the outputs of said smoothing means adapted to perform the weighting of the said outputs of said smoothing means on the basis of said measure.

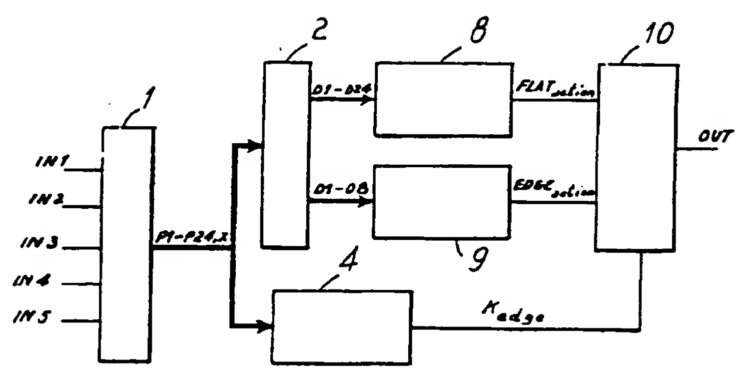

Fig.1

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Description

The present invention relates to a fuzzy device for image noise reduction, better known as a smoother.

As is known, an important problem in the image elaboration field is represented by the implementation of special filters, both linear and non linear, suitable to perform noise reduction.

Within the non linear techniques, several filters based on the Fuzzy Set Theory have been implemented. These filters can distinguish the useful signal information from the noise by means of grammatical elements.

One drawback of known smoothers based on the Fuzzy Logic Theory is that they require a complex hardware implementation.

Furthermore, a very annoying and always occurrent kind of noise is represented by the gaussian noise; its effects are, in fact, difficult to distinguish from the true signal information since they do not spoil too much the gray level of a pixel under study.

Therefore, one of the main problems in the implementation of these kind of smoothers is the choice between the accomplishment of a filter with good noise reduction features, but with small edge preserving properties, and the implementation of a smoother that maintains both high-pass information (edges) and, unfortunately, the noise effects.

Therefore, a principal aim of the present invention is to provide a fuzzy device for image noise reduction suitable to provide for a good noise reduction action whilst preserving the useful high-pass information.

Within the scope of this aim, an object of the present invention is to provide a fuzzy device for image noise reduction which is simpler in architecture than known devices.

Another object of the present invention is to provide a device with good filtering performances in the homogeneous regions of an image whilst preserving and, at the same time, reducing noise effects on edge details.

Another object of the present invention is to provide a device which is highly reliable, relatively easy to manufacture, and at low costs.

This aim, these objects and others which will become apparent hereinafter, are achieved by a fuzzy device for image noise reduction, characterized in that it comprises: interface means adapted to retrieve the gray level of a pixel to be processed of an image and of neighbouring pixels; difference means connected to said interface means adapted to generate a difference in the gray levels between said neighbouring pixels and said pixels to be processed; fuzzy flat area smoothing means connected to said difference means adapted to perform a low-pass smoothing of an almost homogeneous region defined by said pixel and by said neighbouring pixels; edge preserving smoothing means connected to said difference means adapted to perform low-pass filtering on a high-pass information region defined by said pixel and by said neighbouring pixels; region voter means connected to said interface means adapted to give a measure for considering whether said region defined by said pixel and by said neighbouring pixels is almost homogeneous; and soft switching means connected to the outputs of said smoothing means adapted to perform the weighting of said outputs of said smoothing means on the basis of said measure.

Further characteristics and advantages of the invention will become apparent from the description of a preferred but not exclusive embodiment, illustrated only by way of a non-limitative example in the accompanying drawings, wherein:

- figure 1 is a block diagram representing the device according to the present invention;
- figure 2 is a block diagram representing the interface means of the device according to the present invention;
- figure 2a shows the central pixel X which is being processed and the neighbouring pixels P1-P24;
- figure 3 is a block diagram representing the difference means of the device according to the present invention;
- figure 4 is a block diagram representing the region voter means of the device according to the present invention;
- figure 5 is a block diagram representing the fuzzy flat area smoothing means of the device according to the present invention;
- figure 6 is a block diagram representing the edge preserving smoothing means of the device according to the present invention;
- figure 7 is an example of a set of templates employed by the device according to the present invention.

With reference to figure 1, the device is provided with interface means 1 which are adapted to receive, at their inputs IN1-IN5, not only the value of the gray level of the pixel which is being processed but also of the neighbouring pixels.

The interface means 1 are more clearly shown in figure 2. Each input IN1-IN5 is connected to a plurality of delay circuits T, five in the case of this embodiment. The outputs of the delay circuits are the gray levels for a central pixel X, which is being processed, and for the neighbouring pixels P1-P24. The neighbouring pixels P1-P24 and the central pixel X form a matrix as shown in figure 2a. The arrangement of pixels in figure 2a forms a 5x5 window or mask in the image which is being processed. The pixels have been numbered in such a way in order to easily distinguish a 3x3 sub-window formed by the pixels P1-P8 and the central pixels X, of course.

The interface means 1 are connected to difference means 2 adapted to evaluate the differences D_i between the gray levels of the pixels P1-P24 belonging to the mask and the central pixel X. Values are received from the interface means 1. The difference means are more clearly shown in figure 3. The gray level values of the pixels P1-P24 and the gray level value of the central pixel are connected to a subtractor 3 which subtracts the gray

value of X from the individual gray values of each pixel. The difference D_i is given by

$$D_i = P_i - X, \qquad \text{for} \qquad i = 1, \ldots, 24.$$

The output of the interface means 1, constituted by the gray levels of pixels P1-P24 and of the central pixel X, is also connected to region voter means 4. The region voter means 4 are suitable to decide, according to the input parameters, whether the pixel X, which is being processed, belongs to a uniform region of the image or not. For uniform region is meant a region in which there is very little difference in gray levels between the processed pixel and the neighbouring ones. The membership grade is expressed in the interval [0,1]. According to this grade two smoothing actions are performed: Fuzzy Flat Area Smoothing and Edge Preserving Smoothing.

Since one of the aims of the present invention is to provide for a new filter with good filtering performance in the homogeneous regions of the image whilst preserving and at the same time reducing noise effects on edge details, two different actions must be implemented depending on the type of region pointed out by the processing mask of the window. For example, for a uniform (homogeneous) region a 5x5 window mask (pixels P1-P24 and X) has been adopted, whilst for the elaborating of high-pass information, a 3x3 mask (pixels P1-P8 and X) has been chosen.

Larger dimensions of the window used for the homogeneous region guarantee more information on the real structure of the image being processed. On the other hand, in order to preserve high-pass details, it is sufficient to use a smaller mask (3x3) so that the filtering action is not excessively affected by the presence of sharp differences in the gray levels.

The region voter means 4 are adapted to give a measure, expressed in the interval [0,1], for considering whether the region, outlined by a larger 5x5 mask, is homogeneous. An area type parameter p, used for evaluating the type of area being considered, in this case is expressed by

$$p = \frac{\sum_{i=1}^{24} | P_i - x_{ave} |}{23}$$

where P_i is the gray level of each pixel and x_{ave} is the average gray level of all the pixels in the mask.

The region voter means 4 are more clearly shown in figure 4. The region voter means comprise average calculating means 5 which receive, at their inputs, the gray values of pixels P1-P24 and of pixel X and are adapted to calculate the average gray value x_{ave} of such gray values. The output of the average calculating means 5, constituted by the value x_{ave}, is connected to the input of parameter evaluating means 6 which also receive, at its inputs, the gray values of pixels P1-P24 and X and are adapted to perform the calculation described by the above-mentioned equation in order to obtain the area type parameter p.

The output of the parameter evaluating means 6, constituted by the parameter p, is connected to fuzzy processing means 7, which are adapted to determine the degree or grade of membership to the feature (or fuzzy set) "homogeneous region". Such degree of membership K_{edge} constitutes the output of the fuzzy processing means.

Of course, if parameter p is small, then the region outlined by the mask can be considered homogeneous, therefore the fuzzy processing means 7 can be implemented either by using a look-up table (off-line computation) or by employing other simple arithmetic calculations.

The two smoothing actions are performed in accordance with the output values K_{edge}. More specifically, Fuzzy Flat Area Smoothing is weighted with the value K_{edge}, whilst the Edge Preserving Smoothing is applied with the weight $(1 - K_{edge})$.

The Fuzzy Flat Area Smoothing is performed by fuzzy flat area smoothing means 8 whilst the Edge Preserving Smoothing is performed by edge preserving smoothing means 9. The weighting of the actions of the smoothing means 8 and 9 is performed by soft switching means 10, as will be described hereinafter.

The fuzzy flat area smoothing means 8 are more clearly shown in figure 5. Such means perform a low-pass smoothing employing fuzzy IF..THEN..ELSE rules on an almost homogeneous area of the image. Since these smoothing means deal with a homogeneous region, the differences D1-D24 of the larger 5x5 mask are sent to its inputs, i.e. the smoothing action is performed while considering all the differences between the gray levels of the pixels P1-P24 belonging to the study mask and the gray level of the central pixel X of the mask, as provided by the difference means 2.

Each input D1-D24 of the fuzzy flat area smoothing means 8 is connected to a pair of multiplexers: a first multiplexer 11 for the selective passage of positive values and a second multiplexer 12 for the selective passage of negative values. Each multiplexer 11, 12 is enabled by the polarity of the incoming value through lines 16 and 17, i.e. if the value of input D1 is a negative value, it will enable multiplexer 12 through its inverting ENABLE input.

All of the "positive" multiplexers 11 are connected to a positive adder 13 whilst all of the negative multiplexers 12 are connected to a negative adder 14. If any of the differences D1-D24 is positive then the value D+ in the positive adder 13 is increased according to the difference itself, otherwise the value D- in the negative adder 14 is increased accordingly.

The outputs of the adders 13 and 14 are connected to a fuzzy processor 15 which is adapted to establish the smoothing action.

If the value of D+ is HIGH and the value of D- is LOW then almost all the differences D1-D24 outlined by the mask are positive. This means that almost all of the pixels

P1-P24 of the mask have lighter gray levels than the central pixel X. It would therefore appear that the central pixel X has been fired by a negative peak of gaussian noise and must therefore be taken back to a higher gray level. A similar rule can be implemented for the symmetrical case when a positive peak of noise occurs. The rules adopted for the smoothing action are consequently:

IF D+ is HIGH AND D- is LOW THEN $FLAT_{action}$ IS HP
IF D+ is LOW AND D- is HIGH THEN $FLAT_{action}$ IS HP
IF D+ is MED AND D- is LOW THEN $FLAT_{action}$ IS HP
IF D+ is LOW AND D- is MED THEN $FLAT_{action}$ IS HP

where HP and MP stand respectively for high positive and medium positive and similarly HN and MN stand for high negative and medium negative and $FLAT_{action}$ is the output of the fuzzy processing means 15 and of the fuzzy flat area smoothing means 8.

Therefore, the fuzzy process performed by the fuzzy processing means 15 implements some fuzzy IF-THEN rules with two antecendents and one consequent in order to establish the correct smoothing action.

It is however important to stress that this action is not the final smoothing action but has to be combined with the action provided by the edge preserving smoothing means 9.

The edge preserving smoothing means 9 are adapted to perform low-pass filtering on a region that has been considered to be not properly homogeneous by the region voter means 4. This distinction of the type of filtering is necessary if the edge preserving smoothing means 9 are required; in fact, in this manner, the new output value is less affected by the sharp differences of gray levels occurring proximate to an edge.

Edge Preserving Smoothing is accomplished by employing several templates so that it is possible to understand the correct topology of the region of the image outlined by the study mask.

For each predefined template, two simultaneous processes are performed: Fuzzy Template Matching and Fuzzy Edge Smoothing.

Fuzzy Template Matching establishes how much the region outlined by the study mask resembles a particular template. This operation provides a degree of confidence for considering the edge located in the same position as in the one of the predefined template considered.

Fuzzy Template Smoothing, on the other hand, reduces noise effects whilst knowing the structure of the image. In this manner, the smoothing action is not excessively affected by the sharp changes in gray levels occurred with the edges.

Therefore, for each predefined template, a smoothing action is provided in two computational steps: Fuzzy Template Smoothing is accomplished to provide the entity of the smoothing action and Fuzzy Template Matching is used to evaluate the degree of resemblance of the considered template to the particular part of the image outlined by the study mask.

The edge preserving smoothing means are more clearly shown in figure 6. Since these means deal with non-homogeneous regions (high-pass information) they receive at their inputs the differences D1-D8 of the gray levels which are given by the smaller 3x3 sub-window. The difference levels are provided by the difference means 2. Such difference levels are sent to a fuzzy template matcher 18 which is adapted to perform the Fuzzy Template Matching and to a fuzzy template smoother 19 which is adapted to perform the Fuzzy Template Smoothing.

The fuzzy template matcher 18 is adapted to evaluate to which extent the region of the image outlined by the 3x3 window matches with one of the predefined templates. Examples of the predefined templates are shown in figure 7. The comparison with all of the predefined templates allows to understand the real topology of the region of the image outlined by the study mask. By knowing to which kind of template the region under study looks like the most, it is possible to perform a smoothing action without spoiling the output pixel with the sharp differences of the edge. In this manner, high-pass information is certainly preserved.

The fuzzy template matcher 18 calculates a parameter K_i which is used for evaluating the topology of the considered area. Such parameter is given by the following expression:

$$K_i = \frac{\sum_{i=1}^{6} |P_i - X|}{5}$$

where P_i represents gray levels of the pixels belonging to the study mask and X is the gray level of the central pixel to be elaborated. Therefore the parameter K_i is a sum of differences divided by the number of pixels considered only for each template. It is important to point out that the differences are computed considering only the pixels that do not belong to an edge, i.e. the pixels not darkened in figure 7.

If the region of the image outlined by the study mask resembles a particular template, then, certainly, the parameter K_i will have small values. According to this parameter a fuzzy process is performed by the fuzzy template matcher 18 to evaluate the degree of likehood between the region under study and a considered template. Such fuzzy process is similar to the one implemented by the region voter means 4 but on a different kind of area.

It is important to stress that, differently from the region voter means 4, no calculation of the average among the pixels of the mask has to be computed. This presents a significant reduction from a computational point of view, since the average computation operation should have been evaluated for each template, considering every time different "homogeneous" pixels. With the present solution, instead, all the differences are computed only once for all the considered templates and during the evaluation of the matching degree between the region of the image and each template, only the useful differences are employed.

The smoothing of a non uniform region (Fuzzy Template Smoothing) is performed by the fuzzy template smoother 19. The configuration of this smoother 19 is completely similar to the fuzzy flat area smoother 8 (figure 5). The only difference is that the smoothing action is computed by considering the existence of an edge. Again the differences D1-D8 among the gray levels of the pixels P1-P8 of the 3x3 study mask and of the central pixel X are computed. If the differences are positive then the value D+ of the positive adder is increased by the differences themselves, otherwise the value D- of the negative adder is increased. According to the sign of these differences with a fuzzy logic based process an output value of the smoothing action Sm_i is computed.

The overall filtering action $EDGE_{action}$ provided by the edge preserving smoothing means 9 is a weighted sum of the smoothing action Sm_i and of the parameters K_i evaluated by the fuzzy template matcher 18. Therefore, K_i is the level of activation of each template while Sm_i is the smoothing action provided by the fuzzy filter always on each predefined template.

In this particular embodiment only eight templates have been used. The overall smoothing action performed by the edge preserving smoothing means is calculated by processing means 20 according to the following expression:

$$EDGE_{action} = \frac{\sum_{i=1}^{8} | K_i * Sm_i |}{8}$$

Finally, the output $FLAT_{action}$ of the fuzzy flat area smoothing means 8 and the output $EDGE_{action}$ of the edge preserving smoothing means 9 are sent to the soft switching means 10 which are adapted to perform the soft switching between the two different smoothing actions. The weight of the two actions is computed according to the parameter K_{edge} sorted out initially by the region voter means 4, precisely the Fuzzy Flat Smoothing Action - $FLAT_{action}$ is weighted with the value K_{edge} whilst the Edge Preserving Smoothing Action - $EDGE_{action}$ is applied with the weight $(1- K_{edge})$.

As a matter of fact this weighted sum corresponds to the implementation of a fuzzy IF...THEN...ELSE rule where the THEN part is represented by the Fuzzy Flat Smoothing and the ELSE part is represented by the Edge Preserving Smoothing.

In that manner, the soft switching means 10 generate a new output value OUT of pixel X which is being processed.

It is important to stress that the structure of all the blocks described is very simple: most of the blocks require the same operations such as computing the differences among the gray levels of the pixels belonging to the study mask and of the central pixel to be elaborated. All the division operations introduced are given by a division for a constant and consequently are very easy to implement from a hardware point of view. Even the dimensions of the memories employed for storing the fuzzy processes are very restricted.

Therefore a device for noise reduction on video signal has been provided. An efficient smoothing action is performed thanks to the capability of understanding the real topology of the image under process. The soft switching means allow to merge together the two filtering actions performed respectively on a region of the image considered homogeneous and on the one with many high-pass details.

The result of merging a classical approach with a fuzzy logic based approach accomplishes a smoother action with good behaviour both for achieving noise reduction features and for preserving high-pass information (edges). The table-like approach for the fuzzy information storage guarantees the possibility of a very simple implementation.

The invention thus conceived is susceptible to numerous modifications and variations, all of which are within the scope of the inventive concept.

For example masks having different sizes may be used, as well as a larger and more varied group of templates.

Finally, all the details may be replaced with other technically equivalent ones.

In practice, the materials employed, as well as the shapes and dimensions, may be any according to the requirements without thereby abandoning the scope of the protection of the following claims.

Where technical features mentioned in any claim are followed by reference signs, those reference signs have been included for the sole purpose of increasing the intelligibility of the claims and accordingly such reference signs do not have any limiting effect on the scope of each element identified by way of example by such reference signs.

Claims

1. Fuzzy device for image noise reduction, characterized in that it comprises:

   interface means adapted to retrieve the gray level of a pixel to be processed of an image and of neighbouring pixels;

   difference means connected to said interface means adapted to generate a difference of the gray levels between said neighbouring pixels and said pixels to be processed;

   fuzzy flat area smoothing means connected to said difference means adapted to perform a low-pass smoothing of an almost homogeneous region defined by said pixel and said neighbouring pixels;

   edge preserving smoothing means connected to said difference means adapted to perform low-pass filtering on a high-pass information region defined by said pixel and said neighbouring pixels;

   region voter means connected to said interface means adapted to give a measure for considering whether said region defined by said pixel and

said neighbouring pixels is almost homogeneous; and

soft switching means connected to the outputs of said smoothing means adapted to perform the weighting of the said outputs of said smoothing means on the basis of said measure.

2. Fuzzy device, according to the preceding claim, characterized in that said almost homogeneous region is larger than said high-pass information region.

3. Fuzzy device, according to one or more of the preceding claims, characterized in that said edge preserving smoothing means comprise

a fuzzy template matcher adapted to evaluate the resemblance between said region defined by said pixel and said neighbouring pixels and any one of a plurality of templates;

a fuzzy template smoother adapted to perform low-pass filtering on said high-pass information region defined by said pixel and said neighbouring pixels;

processing means connected to the outputs of said fuzzy template matcher and said fuzzy template smoother adapted to generate a weighted sum of said outputs of said fuzzy template matcher and said fuzzy template smoother;

said weighted sum being the output of said edge preserving means.

4. Fuzzy device, according to one or more of the preceding claims, characterized in that said fuzzy template matcher generates a value representative of the level of activation of each of said templates.

5. Fuzzy device, according to one or more of the preceding claims, characterized in that the fuzzy template smoother is adapted to provide a value representative of the filtering action performed on each of said templates.

6. Fuzzy device, according to one or more of the preceding claims, characterized in that said region voter means comprise

average calculating means adapted to calculate the average gray level value of said pixel and of said neighbouring pixels;

parameter evaluating means adapted to calculate the degree of homogeneity of said region defined by said pixel and by said neighbouring pixels;

first fuzzy processing means adapted to generate said measure for considering whether said region defined by said pixel and by said neighbouring pixels is almost homogeneous.

7. Fuzzy device, according to one or more of the preceding claims, characterized in that said fuzzy flat area smoother means comprise

a positive adder adapted to add the positive differences generated by said difference means;

a negative adder adapted to add the negative differences generated by said difference means;

second fuzzy processing means adapted to apply fuzzy inference on the sums of said negative and said positive differences in order to generate the output of said fuzzy flat area smoothing means.

8. Fuzzy device, according to one or more of the preceding claims, characterized in that said difference means comprise a subtractor adapted to generate a difference of the gray levels between said neighbouring pixels and said pixels to be processed.

9. Fuzzy device, according to the preceding claims, characterized in that it comprises one or more of the described or illustrated features.

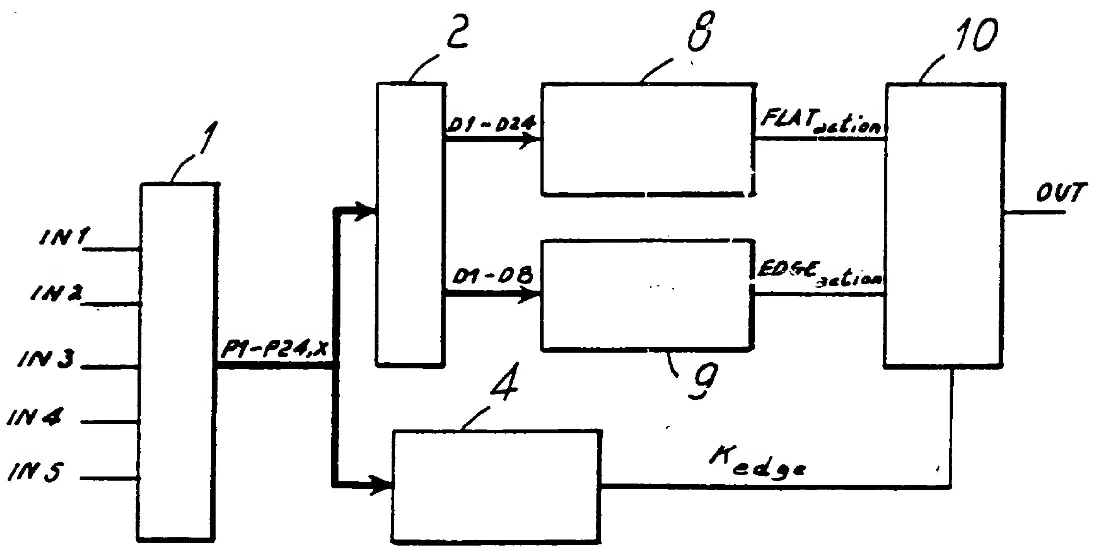
1
2
8
10
4
9
IN1
IN2
IN3
IN4
IN5
P1-P24,X
D1-D24
D1-D8
FLAT action
EDGE action
OUT
K edge

Fig.1

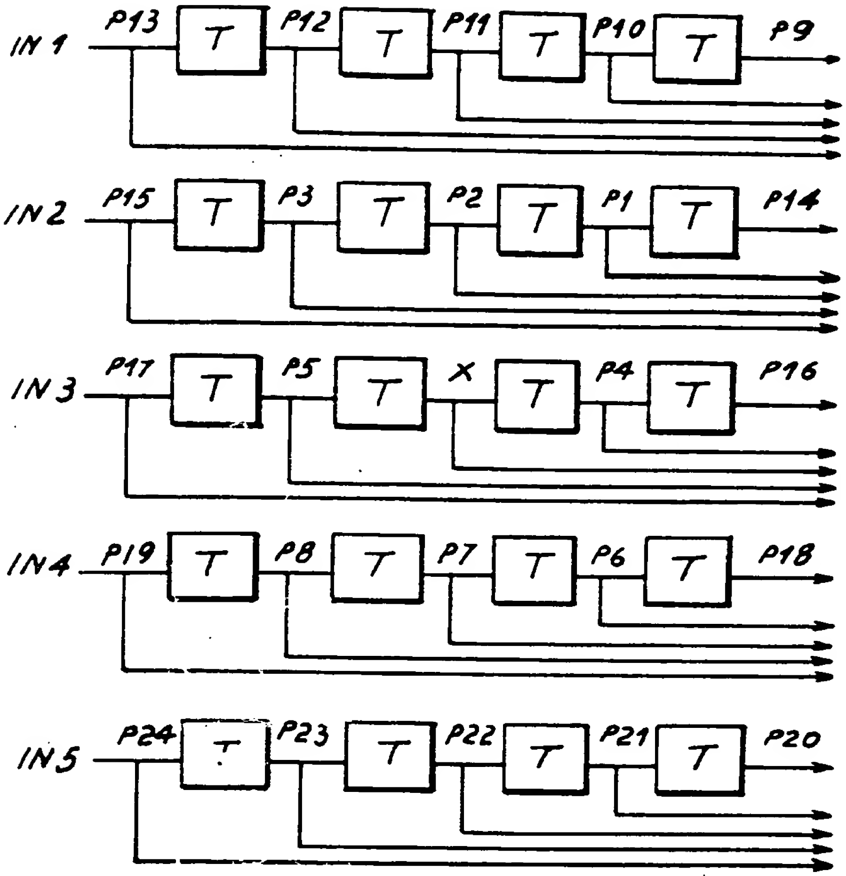

Fig. 2

P9	P10	P11	P12	P13
P14	P1	P2	P3	P15
P16	P4	X	P5	P17
P18	P6	P7	P8	P19
P20	P21	P22	P23	P24

Fig. 2a

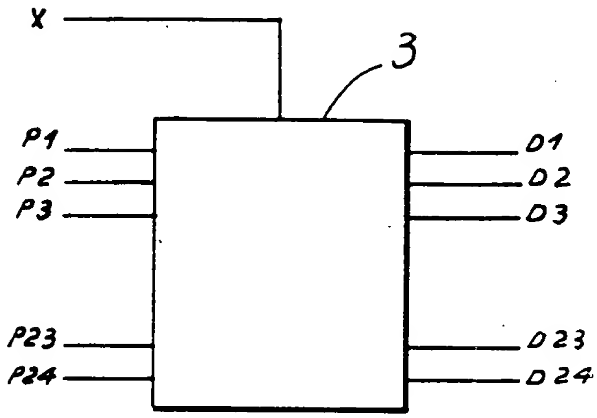

Fig. 3

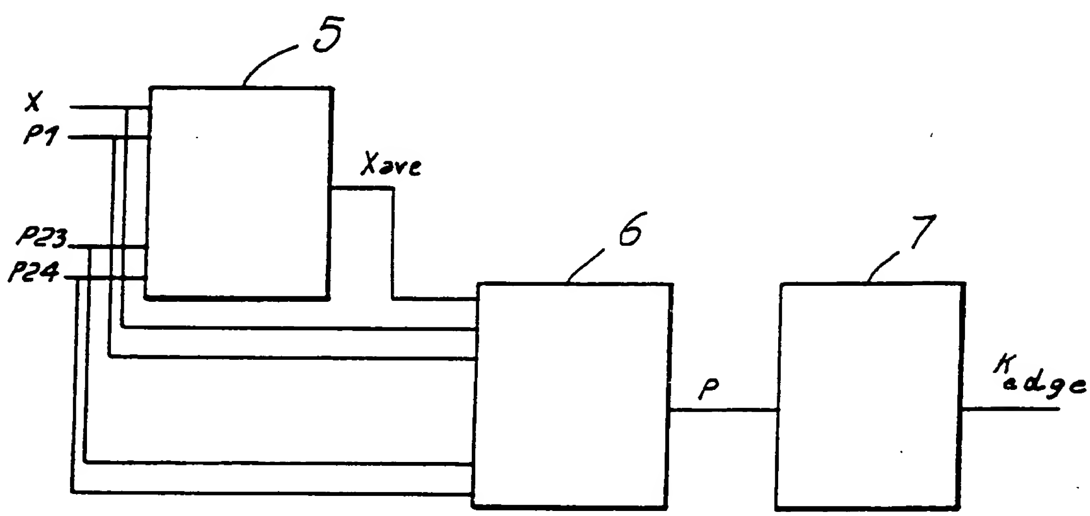

Fig. 4

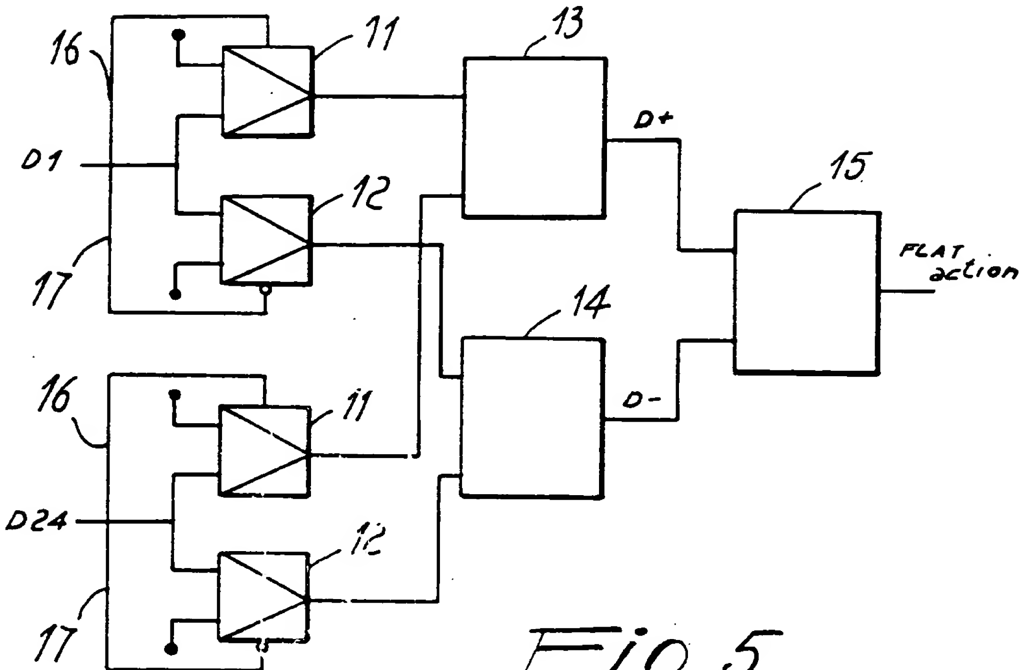

Fig.5

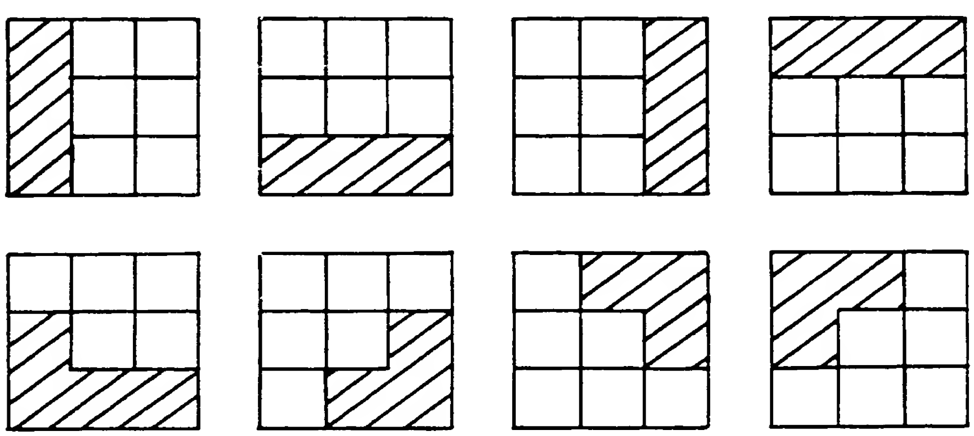

Fig.7

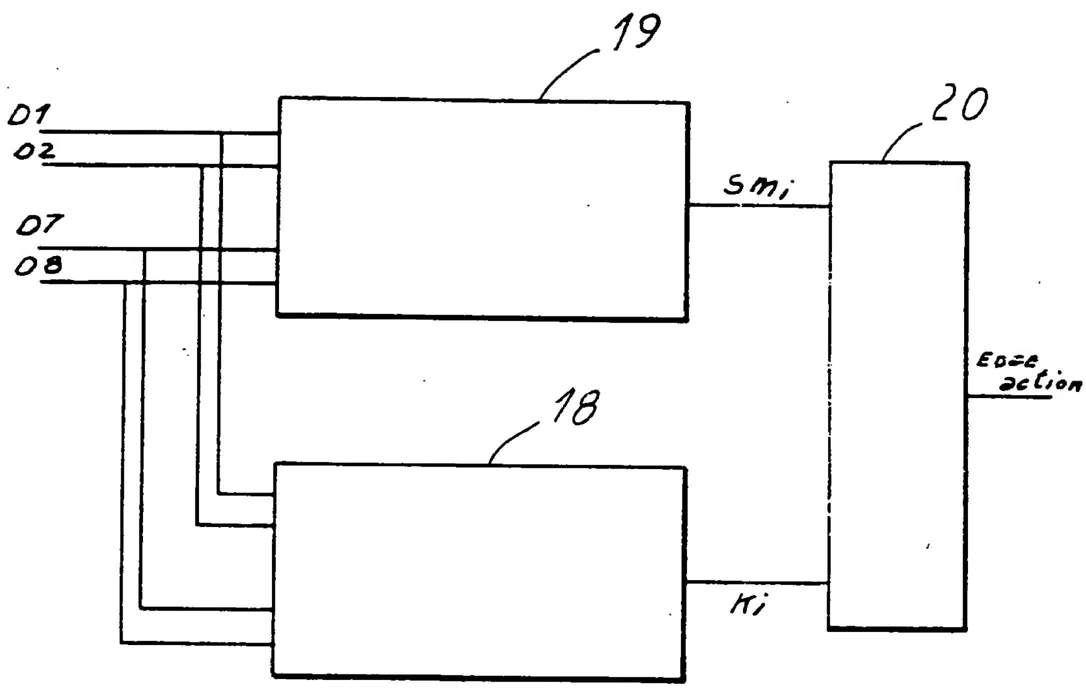

Fig.6